A photometric investigation of the young open cluster Trumpler 15[*]

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ABSTRACT

In this paper we present and analyze new CCD $UBVRI$ photometry down to $V \approx 21$ in the region of the young open cluster Trumpler 15, located in the Carina spiral feature. The cluster is rather compact and has a core radius of about $2'$, which translates in about 1 pc at the distance of the cluster. We provide the first CCD investigation and update its fundamental parameters. We identify 90 candidate photometric members on the base of the position in the color-color and color-magnitude diagrams. This sample allows us to obtain a distance of 2.4±0.3 kpc from the Sun and a reddening $E(B - V)$ =0.52±0.07. We confirm that the cluster is young, and fix a upper limit of 6 million yrs to its age .

In addition, we draw the attention on the lower part of the Main Sequence (MS) suggesting that some stars can be in contracting phase and on a gap in the MS, that we show to be a real feature, the $B1 - B5$ gap found in other young open clusters.

We finally study in details the extinction toward Trumpler 15 concluding that it is normal and suggesting a value of 2.89±0.19 for the ratio of total to selective absorption R_V.

Key words: Open clusters and association–Individual: Trumpler 15

1 INTRODUCTION

In this paper we study the stellar content of the young compact open cluster Trumpler 15 by means of deep multicolor CCD photometry.

This open cluster (α = 10:44:33.0, δ = -59:24:24.0, l = 287.41, b = -0.41; J2000.0) is located near the northern edge of the Great Carina Nebula (NGC 3372), about $20'$ above η Carinæ . It is also named VdB-Hagen 104, Lund 558 and OCL 825.

Like other young clusters in this region (e.g. Trumpler 14 and 16), is rather compact and rich. There are several intriguing questions related to this cluster, which was discussed in the past often leading to contradictory results. Is the interstellar extinction toward Trumpler 15 normal? Is this cluster connected with the other ones located much closer to η Carinæ , like Trumpler 14, 16 and Collinder 232? In other words, does it share the same properties of these clusters, like age and distance, suggesting that it probably formed together with them in the same Star Formation event?

Aiming at clarifying these issues and deriving updated estimates for its fundamental parameters, like distance and age, in this paper we present and discuss the first $UBVRI$ CCD photometric study of Trumpler 15.

The layout of the paper is as follows: Section 2 presents briefly the data acquisition and reduction. In Section 3 we discuss previous investigations on this cluster; in Section 4 we compare our photometry with previous ones and present our data. Section 5 illustrates the technique to derive reddening and membership of stars in Trumpler 15. Section 6 is dedicated to the study of the interstellar extinction toward the cluster, while in Section 7 we derive estimates for Trumpler 15 age and distance. Finally, Section 8 discusses the geometrical structure of the cluster and Section 9 summarizes our findings.

2 OBSERVATIONS AND DATA REDUCTION

Observations of four $3'.2 \times 3'.2$ overlapping fields in the region of Trumpler 15 were conducted at La Silla on April 16, 1996, with the 0.92m ESO–Dutch telescope. The observations strategy, the data reduction and the error analysis have been presented in Patat & Carraro (2001), which the

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[*] Based on observations carried out at ESO La Silla; Data are available at the WEBDA site: http://obswww.unige.ch/webda/
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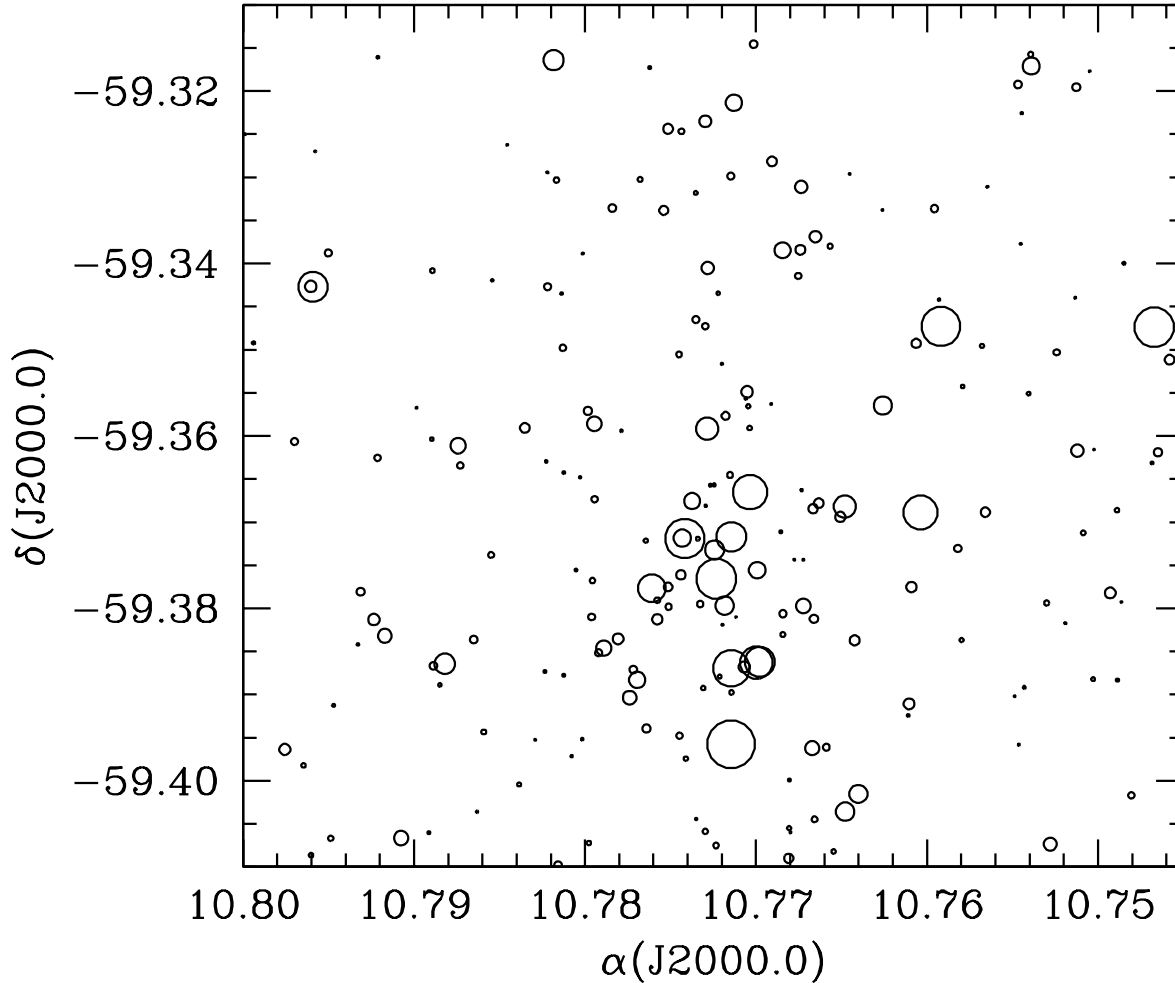
Figure 1. A map of a observed region around Trumpler 15. The size of each star is proportional to its magnitude. North is up, East on the left. The field is about $6' \times 6'$.

reader is referred to for any detail. Briefly, the night was photometric with an average seeing of 1.0 arcsec. In the same night we observed NGC 3324, a young open cluster in the same region, about which we reported elsewhere (Carraro et al 2001). The log-book of the observations reporting the filters used, the integration times and the seeing of each frame is given in Table 1, whereas a map of the covered region is shown in Fig. 1. We performed Point Spread Function (PSF) photometry and corrected stellar magnitudes for aperture corrections, since standard stars were measured by performing aperture photometry (Patat & Carraro 2001). Our photometry is rather accurate: typical global RMS errors are 0.03, 0.04 and 0.07 at $V = 12$, 20 and 21, respectively

(see Patat & Carraro 2001).
The complete photometry of Trumpler 15 will be available at the WEBDA site[‡].

3   PREVIOUS STUDIES

3.1   Photometric investigations

Trumpler 15 was firstly studied by Grubissich (1968) and Thé & Vleeming (1971). These latter provided UBV photo-

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[‡] http://obsww.unige.ch/webda/navigation.html

Table 1. Journal of observations of Trumpler 15 (April 16 , 1996)

Field	Filter	Time integration (sec)	Seeing (″)
#1			
	U	30	1.2
	B	10	1.2
	B	300	1.0
	V	3	1.1
	V	120	1.1
	R	1	1.0
	R	60	1.0
	I	3	1.1
	I	120	1.0
#2			
	U	30	1.0
	B	10	0.9
	B	300	0.9
	V	3	0.9
	V	120	0.8
	R	1	0.8
	R	60	0.9
	I	3	1.0
	I	120	1.1
#3			
	U	20	1.0
	B	3	1.1
	B	300	1.1
	V	3	1.0
	V	120	1.0
	R	1	1.0
	R	60	1.0
	I	3	1.0
	I	120	1.1
#4			
	U	20	1.1
	B	3	1.0
	B	300	1.0
	V	3	1.0
	V	120	1.0
	R	1	1.0
	R	63	1.1
	I	5	1.1
	I	120	1.1

Figure 2. A comparison of our photometry with Thé & Vleeming (1971) study. The comparison is in the sense (this study - Thé & Vleeming).

graphic photometry for 25 stars down to $V = 13$, confirming previous suggestions by Grubissich (1968) that the cluster is very young. Moreover they find that the cluster is closer to us than Trumpler 14 and 16, at about 1.6 kpc.

A more detailed study has been carried out by Feinstein et al (1980), who measure 48 stars in $UBVRI$ using an RCA 1P21 photo-multiplier down to $V = 14$. They identify 24 candidate members, and suggest that probably other 12 stars can be members of the cluster.

While they basically confirm the cluster age, they significantly revise the distance, putting Trumpler 15 at 2.6±0.2 kpc, roughly at the same distance of Trumpler 14 and 16. From the analysis of their photometry they conclude that the reddening law in the direction of the cluster is normal and that the mean color excess is E$(B - V) = 0.48 \pm 0.07$. Trumpler 15 was also observed in the Walraven photometric system by Thé et al (1980) who found a distance of 2.5 kpc and a very low reddening E$(B - V) = 0.189$.

Finally, Tapia et al (1988) present $JHKL$ near infra-red

photometry for 35 stars and, at odds with Feinstein et al (1980), claim that the interstellar extinction toward Trumpler 15 is not normal and report a ratio of total to selective absorption $R_V = 4.0$, significantly higher than the widely accepted value of 3.1, which instead seems to hold for all the other clusters in the vicinity of η Carinæ (Feinstein et al 1973).

In conclusion there seems to exist a general disagreement in all the major properties of Trumpler 15, but for the age.

3.2 Spectroscopic investigations

Photographic spectroscopy of 21 stars in the field of Trumpler 15 has been carried out by Morrell et al (1988). This investigation led to the spectral classification of the studied stars, all with magnitude brighter than $B = 13$. There stars were found to range from O to $B9$ spectral type. For some of these stars the classification were already been obtained by Feinstein et al(1980), and the two sources compare very nicely.
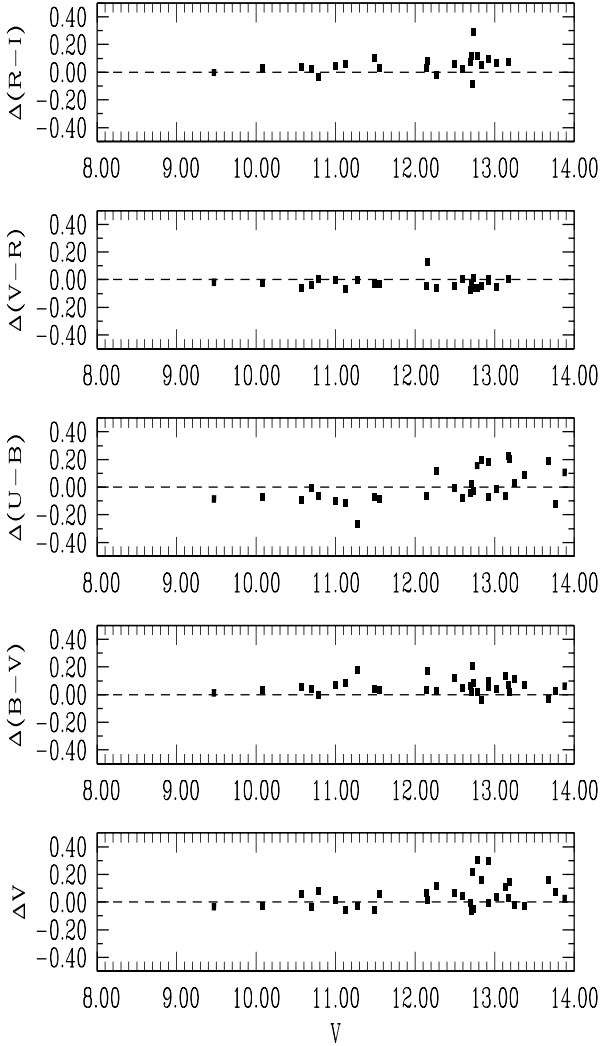
Figure 3. A comparison of our photometry with Feinstein et al (1980) study. The comparison is in the sense (this study - Feinstein et al).

4   THE PRESENT STUDY

We provide $UBVRI$ photometry for 1404 stars in a $6'.2 \times 6'.2$ region centered in Trumpler 15, up to about $V = 21$. The region we sampled is shown in Fig. 1, where a V map is presented. In this map North is on the top, East on the left. The stars are plotted according to their magnitude. Open symbols are used to illustrate how blending situations are actually present.

Fig. 2 and 3 present a comparison between our photometry and Thé & Vleeming (1971) and Feinstein et al (1980), respectively.

A comparison with Thé & Vleeming (1971) photometry is shown in Fig. 2 for 16 stars in common. From this sample we find

$$V_C - V_{TV} = 0.08 \pm 0.18$$

$$(B - V)_C - (B - V)_{TV} = -0.01 \pm 0.09$$

$$(U - B)_C - (U - B)_{TV} = -0.28 \pm 0.13,$$

where the suffix C stands for the present work, while TV stands for Thé & Vleeming (1971). The difference is large only for $(U - B)$, but the scatter is large in all the relations, as can be noticed also by inspecting Fig. 2. It is important to stress that the field is rather crowded and unevenly obscured, and usually photographic photometry performs badly at the faint magnitude end and in cases of blended stars. Thé & Vleeming (1971) point out that they were not able to measure the three brightest stars in the cluster core (see Fig. 1) due to blending.

The larger difference is in the $(U - B)$ color. Such discrepancy is reported also by Feinstein et al (1980), who in fact report differences with Thé & Vleeming (1971) of 0.01±0.12, 0.07±0.15, and 0.42±0.16 for V, $(B - V)$ and $(U - B)$, respectively. Although for V and $(B-V)$ there is a good agreement, nonetheless the scatter is quite large. Apparently, a calibration problem with $(U - B)$ exists in Thé & Vleeming (1971), and most probably the reason of the scatter is an unaccounted color term in the photographic measurements, as the solid line in Fig. 2 (upper panel) would seem to indicate.

We have compared our photometry with Feinstein et al (1980) for 33 common stars. The results are shown in Fig. 3. We obtain

$$V_C - V_{FFM} = 0.03 \pm 0.08$$

$$(B - V)_C - (B - V)_{FFM} = 0.05 \pm 0.09$$

$$(U - B)_C - (U - B)_{FFM} = 0.06 \pm 0.15$$

$$(V - R)_C - (V - R)_{FFM} = -0.03 \pm 0.05$$
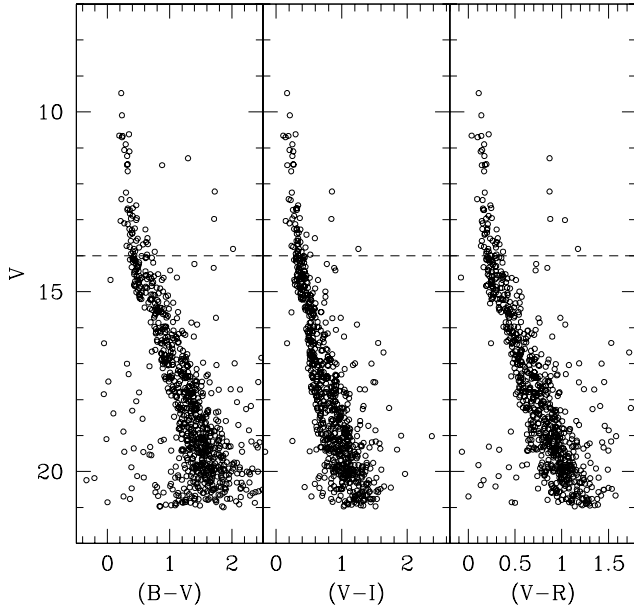
$$(R - I)_C - (R - I)_{FFM} = +0.02 \pm 0.06$$

where the suffix FFM refers to Feinstein et al (1980). It appears that the two photometries are basically consistent within the errors. However, the scatter is significant. We already reported in other studies (Carraro et al 2001, Patat & Carraro 2001) significant scatter when comparing photoelectric and CCD photometry, especially for the cases of young compact clusters like NGC 3324 and Bochum 11. The reasons for such scatter can be blending effects, stars variability, uneven obscuration and so forth. We believe that the main source of error is the difficulty of photoelectric aperture photometry in dealing with crowded fields. For instance in the case of Trumpler 15, we found that the stars #14 (Grubissich numbering) is actually a blend of two stars that thanks to the good seeing conditions we were able to separate. Another case for which the difference is huge is stars #11, which has a close poorly resolved companion.

Finally, we have compared our photometry with the Walraven photometry from Thè et al (1980). To perform the comparison, we translated the Walraven $(V - B)$ color into the Johnson $(B - V)$ color by using the relation

$$(B-V)_J = 2.571 \cdot (V-B) - 1.020 \cdot (V-B)^2 + 0.500 \cdot (V-B)^3 - 0.01 \quad (1)$$

which is valid for $(V - B)$ smaller than 0.45. By considering all the stars in common (22) we obtain:

$$(B - V)_{TBA} - (B - V)_C = -0.048 \pm 0.075$$

Figure 4. The CMDs of Trumpler 15 including all the detected stars.

Figure 5. Two color diagram for stars in the field of Trumpler 15 having UBV photometry. Filled circles indicate stars having mean reddening $E(B-V) = 0.52 \pm 0.07$ (r.m.s.), open squares stars with larger reddening The solid line is the empirical ZAMS from Schmidt-Kaler (1982), whereas the dashed lines are the same ZAMS, but shifted by $E(B-V) = 0.30$ and by $E(B-V) = 0.70$, respectively.

However, four stars - Grubissich (1968) numbers 2, 6, 8 and 22 deviate significantly (see also Feinsten et al 1980). By excluding these stars, we obtain

$$(B-V)_{TBA} - (B-V)_C = -0.037 \pm 0.038$$

which indicates that the two photometries are consistent within the errors. From the comparison we have excluded stars #14, that we have already shown to be a blend of two stars.
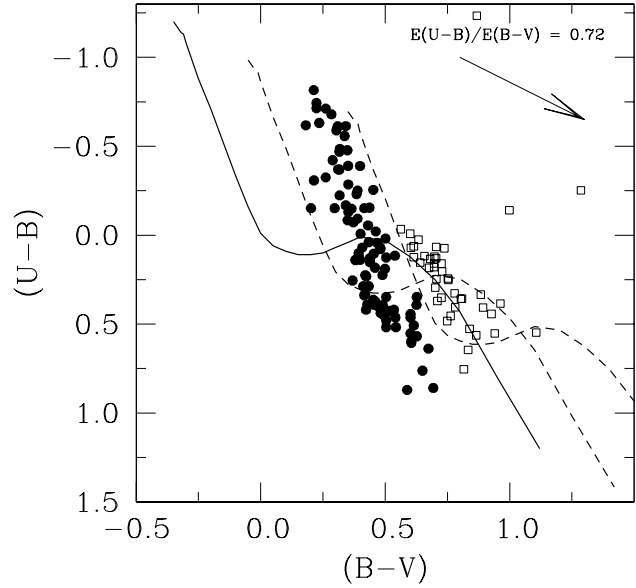
The CMDs for all the measured stars is plotted in Fig. 4 in the planes $V - (B-V)$, $V - (V-I)$ and $V - (V-R)$. The dashed line indicates the magnitude limit of Feinstein et al (1980) photoelectric photometry, the deepest one before the present study.

Our photometry reaches $V \approx 21$, and the Main Sequence (MS) extends for about 10 mag. It gets wider at increasing magnitude, due to :

- some -but not severe- field star contamination;
- photometric errors, which typically amount at $\Delta(B-V) = 0.04$, 0.10 and 0.15 at $V = 12.0$, 16.0 and 20, respectively.
- the presence of unresolved binary systems, whose percentage in these clusters is around 30% (Levato et al 1990).

Two interesting features are worth to be noticed:

1) the presence of a prominent gap at $V \approx 12$, $(B-V) \approx 0.2$;
2) a change of slope in the MS at $V \approx 14.5$, which is a hint for a possible *turn on*.

5 INDIVIDUAL REDDENINGS, MEMBERSHIP AND DIFFERENTIAL REDDENING

We use UBV photometry to derive stars' individual reddenings and membership, and the analysis strictly follows Carraro & Patat (2001) and Patat & Carraro (2001). Basically we determine individual reddenings by means of the reddening free parameter Q and the distribution of the stars in the $(U-B) - (B-V)$ diagram.

5.1 Individual reddening and membership

The color-color diagram for all the stars having UBV photometry (142 stars in total) is shown in Fig. 5. In this plot the solid line is an empirical ZAMS taken from Schmidt-Kaler (1982).

The bulk of the stars are confined within a region defined by two ZAMS shifted by $E(B-V) = 0.30$ and 0.70 (dashed lines), respectively. The stars which occupy this region amount to 90 and have a mean reddening $E(B-V) = 0.52 \pm 0.07 (r.m.s.)$.

Since the spread in reddening is larger than the photometric errors, which are typically $\Delta(U-B) \approx \Delta(B-V) \approx 0.04$, this indicates the possible presence of differential reddening across the cluster.

There seems to be another population of stars more

Table 2. Photometric candidate members of the open cluster Trumpler 15 having spectral classification. This is taken from Morrell et al (1988). In the second column we list the numbering from Grubissich (1968).

ID	Grub.	*Sp. Type*	α	δ	V	$(B-V)$	$(U-B)$	$(V-R)$	$(R-I)$
2	2	O9-III	10:42:47.08	-59:05:29.50	9.438	0.213	-0.816	0.091	0.168
3	15	B0.5-IV	10:42:44.70	-59:07:14.80	10.054	0.224	-0.743	0.119	0.210
4	26	B1-V	10:42:31.80	-59:04:18.00	10.663	0.224	-0.714	0.079	0.144
6	7	B2.5-V	10:42:46.11	-59:06:01.70	10.582	0.337	-0.558	0.198	0.298
7	3	B2 -V	10:42:47.76	-59:05:43.10	10.627	0.235	-0.631	0.119	0.188
8	13	B1-V	10:42:45.45	-59:06:41.60	10.861	0.284	-0.680	0.149	0.248
9	4	B1-V	10:42:43.92	-59:05:24.70	11.019	0.261	-0.712	0.127	0.204
10	23	B0-V	10:42:33.86	-59:05:39.35	11.059	0.342	-0.613	0.111	0.263
15	5	B5-V	10:42:45.06	-59:05:45.60	11.431	0.304	-0.590	0.157	0.267
17	10	B2-V	10:42:49.77	-59:06:05.20	11.609	0.316	-0.470	0.148	0.230
18	18	O9-I	10:42:39.82	-59:08:32.20	11.250	1.286	-0.252	0.850	-1.119
25	9	B1-V	10:42:45.30	-59:06:16.30	12.636	0.399	-0.389	0.224	0.321
26	25	B5-V	10:42:32.90	-59:04:50.00	12.682	0.311	-0.370	0.141	0.256
28	19	09-V	10:42:32.70	-59:07:40.00	12.646	0.316	-0.369	0.136	0.305
42	22	B9-V	10:42:40.80	-59:06:18.70	13.200	0.431	-0.055	0.184	0.315
44	21	B0-III	10:42:05.00	-59:07:20.00	13.242	0.385	-0.231	0.180	0.315
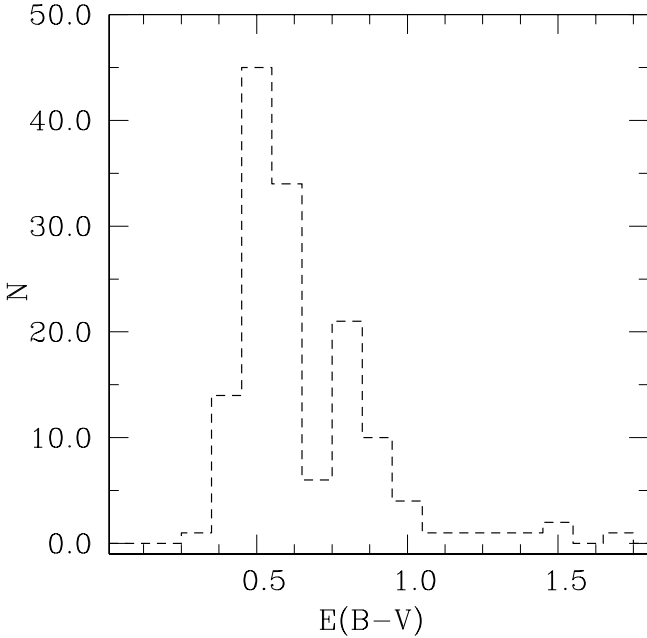
Figure 6. Individual reddening distribution for stars in the field of Trumpler 15 having UBV photometry.

reddened, which lies beyond the ZAMS shifted by $E(B-V) = 0.70$ and clearly detaches from the previous group. These stars are indicated with open squares, and have a mean reddening $E(B-V) = 0.92 \pm 0.22 (r.m.s.)$.

Some additional indications in this sense derive also from Fig. 6, where we plot the individual reddenings distribution function. A clear peak is centered at $E(B-V) \approx 0.50$, while a second well separated peak is visible, centered at $E(B-V) \approx 0.80 - 0.90$. In any case there is a large spread in reddening, which suggests again the presence of differential reddening across the cluster, as recently found also by

Yadav & Sagar (2001).

As a working hypothesis, we shall consider as candidate cluster members the stars having $E(B-V) = 0.52\pm0.07$, and investigate how they distribute in the reddening corrected CMDs. In Fig. 7 we plot the reddening corrected CMDs in the planes $V_o - (B-V)_o$ (left panel) and $V_o - (U-B)_o$ (right panel) using the same symbols as in Fig. 5, and by provisionally adopting $R_V = 3.0$ (Feinstein et al 1980). All the stars brighter than $V_o < 11.5$ define a nice sequence. There is just one exception, which is the star #18 (Grubissich numbering) which has a very large reddening. The analysis of its colours (see Table 2) seems to support the idea that this star is actually a blend of two stars, a blue supergiant with a red companion (see also the discussion in Feinstein et al (1980). Further sprectra are necessary to better clarify this issue.

Below $V_o = 11.5$ stars having smaller reddening start to mix with stars having larger reddening. We interpret this fact in the sense that up to $V_o = 11.5$ Trumpler 15 clearly emerges from the background, whereas below this magnitude it smoothly merges with the general Galactic disk field. This fact was not evident in previous photometry which were not sufficiently deep. A final check is to look at the spatial distribution of members and non-members in the field of the cluster. This is presented in Fig. 8, where again filled circles represent candidate members and open squares indicate candidate non-members. It seems that our selection criterion of members and non-members worked fine, since member stars, as expected, tend to concentrate in the cluster core, whereas non-members preferentially distribute in the cluster outskirts.

In conclusions, we suggest that the 90 stars having $E(B-V) = 0.52 \pm 0.07$ are probable members, whereas all the other stars having $E(B-V) = 0.92 \pm 0.22$ are field stars. It is worth noticing here that in a recent work DeGioia-Eastwood et al (2001) found that the field stars in a region

close to η Carinæ have indeed a reddening $E(B-V) \approx 1.0$.

Morrell et al (1988) provide spectral classification of 21 stars in the field of Trumpler 15. We have combined the common stars (16) to obtain absolute magnitudes and colors and derive another estimate of the cluster mean reddening. These stars are listed in Table 2. We derive the reddening $E(B-V)$ by adopting the intrinsic color indices of OB giants, supergiants and dwarf stars in the $UBVRIJHKLM$ system provided by Wegner (1994). For the 16 stars in Table 2 we obtain $E(B-V) = 0.52 \pm 0.06$, in perfect agreement with the mean reddening derived from the analysis of the color-color diagram. This result makes us confident when using the photometric probable candidate members above derived.

5.2 Differential reddening

As already outlined, the large reddening spread visible in Figs 5 and 6 can be due to the presence of differential reddening across the cluster. This possibility has been already discussed by Yadav and Sagar (2001) by using data from the literature, and confirmed by the mid-infrared observations obtained by Smith et al (2000, fig. 2) with the MSX satellite, which show how the region of Trumpler 15 is unevenly obscured.

It is interesting to look for a possible relation of the color excess of each candidate member with its position on the plane of the sky, which would confirm the presence of patchy absorption. To this aim, we plotted in Fig. 9 the distribution of colour excesses across the cluster. In this figure the size of the points is proportional to the color excess. By inspective this plot one can readily recognizes how the obscuration toward Trumpler 15 is really irregular.

6 THE EXTINCTION TOWARD TRUMPLER 15

There is some disagreement in the literature whether the extinction toward this cluster is normal ($R_V =3.0$, Feinstein et al 1980) or anomalous (larger R_V, Tapia et al 1988).
A recent estimate of $R_V = 4.0$ is reported by Patriarchi et al (2001), but is based on just one star (# 18) which actually is a blend of two stars, as discussed above.
In this section we want to re-investigate this problem by using our $UBVRI$ data combined with near IR $JHKL$ data from Tapia et al (1988) and spectral classifications from Morrell et al (1988).

6.1 UBV data

UBV data can be used to derive an estimate of the R_V parameter, defined as the ratio of the total to selective absorption $\frac{A_V}{E(B-V)}$, by means of the variable extinction method (see, for instance, Johnson 1966a). This method requires also the knowledge of the absolute magnitude and intrinsic colors of individual member stars. We use the empirical ZAMS taken from Schmidt-Kaler (1982) to derive absolute magnitude and intrinsic colors.
The result is shown in Fig. 10, where all the probable photometric members selected in the previous Section have been
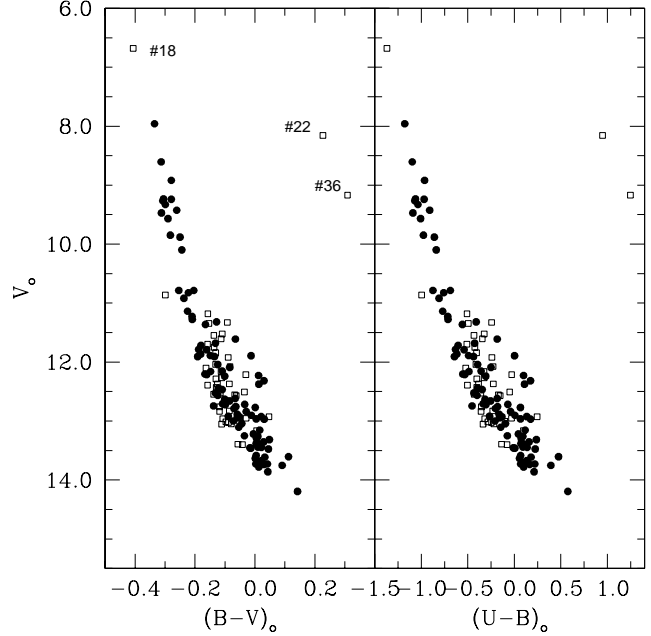
Figure 7. Reddening corrected CMDs for stars in the field of Trumpler 15 having UBV photometry. Symbols are as in Fig. 5. Some interesting stars have been labeled with their Grubissich number.
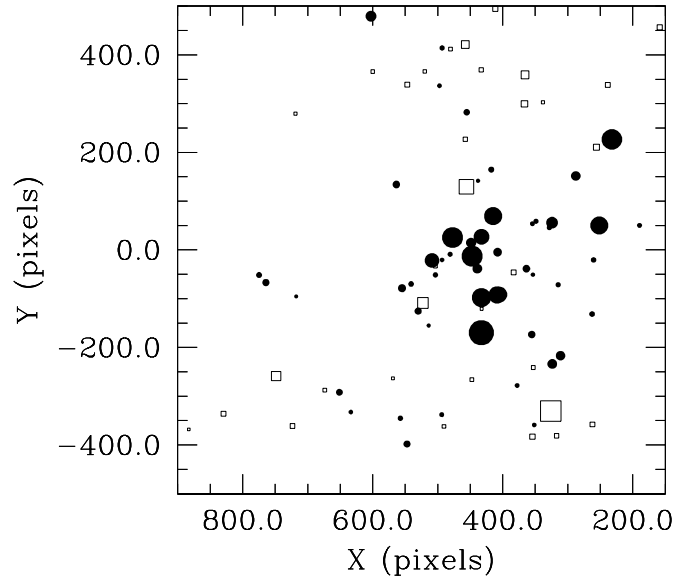
Figure 8. Spatial distribution of candidate members and non-members in the field of Trumpler 15 having UBV photometry. Symbols are as in Fig. 5 and the size of the stars is proportional to their magnitudes.
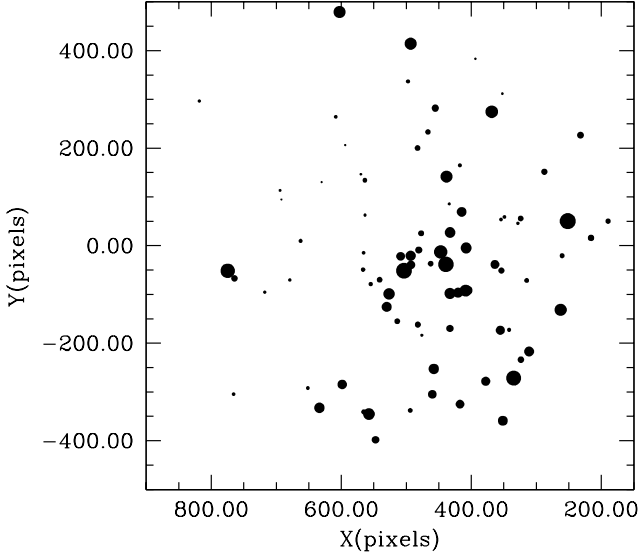
Figure 9. Spatial distribution of color excesses of the candidate member stars in the field of Trumpler 15. The size of each star is proportional to its color excess.

Figure 10. Differential reddening plot for all the MS stars in the studied region. The solid line is a least squares fit through the data.

considered. The least squares fit through the data provides $R_V = 2.89 \pm 0.28$. The absolute distance modulus, defined as the ordinate for $E(B - V) = 0$, turns out to be $(m - M)_0 = 11.90 \pm 0.25$, which implies a distance from the Sun of 2.4 ± 0.3 kpc.

The reported errors are the results of the linear fit, obtained by assuming that both the color excesses and the magnitueds have their uncertainty. However, due to the small range in color excess, the result we obtained has to be considered -with some caution- as no more than an indication.

6.2   Near IR data

To obtain another estimate of R_V we combine our $UBVRI$ photometry with the near IR photometry in the $JHKL$ bands from Tapia et al (1988). We have 30 stars in common, but we perform our analysis only by considering the star having spectral classification. Basically, there are two methods to derive and estimate of R_V from near IR photometry.
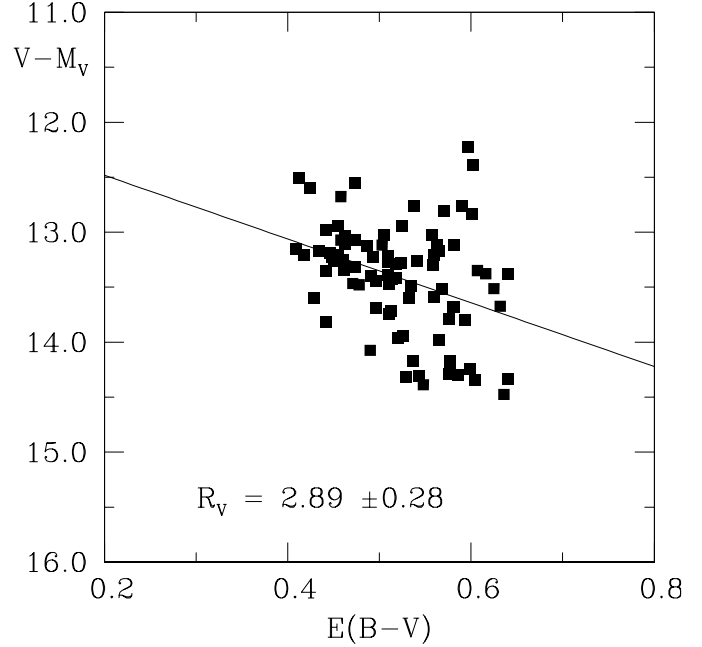
The first method *(a)* is based on the following approximate relation

$$R_V \approx 1.1 \times \frac{E(V - K)}{E(B - V)}, \tag{2}$$

reported by Whittet (1990). We use Wegner (1994) intrinsic colour indices to derive the color excess $E(B-V)$ and $E(V-K)$. The mean value for the stars in Table 2 turns out to be

$$R_V = 2.77 \pm 0.33 (r.m.s.)$$

in fine agreement with the variable extinction method.

The second method *(b)* makes use of the extinction curve, and was devised by Morbidelli et al (1997). From

the observed IR fluxes, the colour excesses $E(\lambda - V)$ have been found using the intrinsic colours by Wegner (1994). The quantity A_V has then been determined with a least squares solution, by fitting (Cardelli et al, 1989):

$$E(\lambda - V) = A_V \times (R_L(\lambda) - 1) \tag{3}$$

where $\lambda = R, I, J, K, L$ and R_L is the extinction curve $\frac{A_\lambda}{A_V}$ taken from Rieke & Lebofsky (1985).

From the derived A_V and the known $E(B - V)$ we obtain R_V. Since the fitting equation 3 is a homogeneous one, the uncertainty of each A_V hase been computed by considering that we have $N - 1$ degree of freedom (N being the number of photometric bands available). This implies that we can obtain only a lower limit on the R_V uncertainty, since it is not easy to take into account spectral mis-classification and hence inaccuracy in the adopted intrinsic colors (Patriarchi et al 2001).

The results are summarized in Table 3, where the identification is reported together with the individual reddening $E(B - V)$, the total absorption A_V, and the ratio of total-to-selective absorption $R_V = \frac{A_V}{E(B-V)}$, these latter derived from the method *(b)*. The last column reports the value of R_V derived from the method *(a)*. A weighted mean yields $R_V = 3.09 \pm 0.44$. in fine agreement both with the results of method *(a)*, and with the finding of the differential reddening method. In fact the three values we obtain for R_V clearly overlap, and a weighted mean yields the final estimate

$$R_V = 2.89 \pm 0.19,$$

which means that the interstellar reddening law toward Trumpler 15 appears normal, as previously suggested for instance by Feinsten et al (1980).

Table 3. Extinction parameters of Trumpler 15 stars with near IR photometry and spectral classification.

ID	Grub.	Sp. Type	$E(B-V)$	A_V	$R_V,(b)$	$R_V,(a)$
2	2	O9-III	0.473	1.36±0.05	2.87±0.13	2.23
3	15	B0.5-IV	0.464	1.29±0.13	2.78±0.16	2.92
4	26	B1-V	0.454	1.15±0.21	2.53±0.29	2.48
6	7	B2.5-V	0.532	1.79±0.17	3.36±0.25	2.98
7	3	B2 -V	0.445	1.50±0.33	3.37±0.41	2.96
8	13	B1-V	0.514	1.45±0.11	2.82±0.20	2.68
9	4	B1-V	0.491	1.25±0.09	2.55±0.17	2.37
10	23	B0-V	0.602	2.10±0.24	3.49±0.37	2.59
15	5	B5-V	0.454	1.49±0.07	3.28±0.15	2.47
17	10	B2-V	0.526	1.45±0.13	2.76±0.22	2.61
18	18	O9-I	1.556	6.98±0.39	4.48±0.65	3.45
25	9	B1-V	0.629	2.42±0.19	3.85±0.32	3.19
26	25	B5-V	0.461	1.58±0.23	3.42±0.40	2.96
28	19	09-V	0.596	1.43±0.19	2.40±0.35	2.41
42	22	B9-V	0.501	1.70±0.16	3.39±0.30	2.83
44	21	B0-III	0.615	2.30±0.31	3.74±0.46	3.19
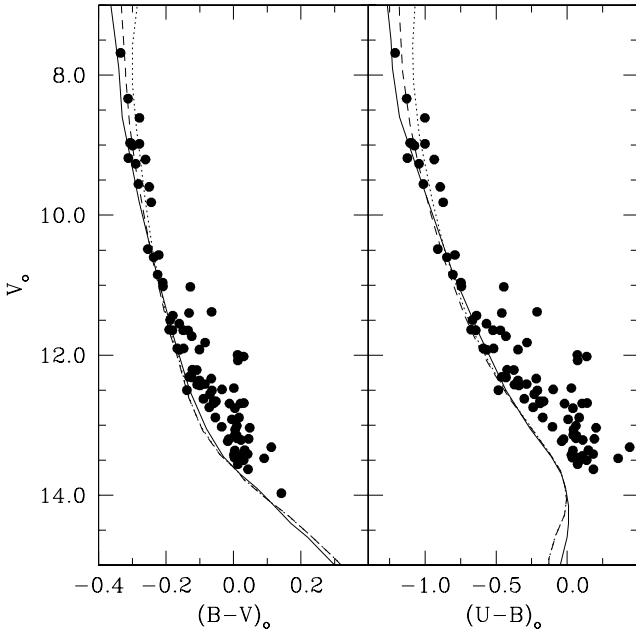
Figure 11. Reddening corrected CMD for the stars members of Trumpler 15. The solid line is the empirical ZAMS form Schmidt-Kaler (1982) Super-imposed are post MS isochrones from Girardi et al 2000 (dashed and dotted lines). See text for more details.

7 AGE, DISTANCE AND PRE MS CANDIDATES

We already obtained an estimate of Trumpler 15 distance from the analysis of the variable extinction plot in Section 6. Here we address the issues of the distance and the age directly by considering the reddening corrected CMDs for the member stars. The correction to the magnitudes is done by computing $V_o = V - 3.0 \times E(B-V)$ for each star. This is plausible since we have shown that the reddening law in the direction of the cluster is normal.

7.1 Age and Distance

The reddening corrected CMDs in the planes $V_o - (B-V)_o$ and $V_o - (U-B)_o$ are showed in the left and right panel of Fig. 11, respectively. The solid line super-imposed is the Schmidt-Kaler (1982) ZAMS shifted by $(m-M)_o = 11.90$, which fits the blue edge of the stars distribution, supporting the distance modulus estimate derived in the previous Section.

The brightest stars depart somewhat from the ZAMS, suggesting that they are evolving toward the Red Giant region. This is confirmed by the location of the dashed and dotted lines, which are a 2 (dashed line) and 6 (dotted line) million yrs solar metallicity isochrones taken from Girardi et al (2000). The bright evolved stars lie between the two isochrones implying that the age of this cluster is between 2 and 6 million yrs.

7.2 A gap in the MS?

Also in these diagrams a gap appears at $V_o \approx 10.5$, $(B-V)_o \approx -0.25$, which means that the gap is not affected by the removal of non-members.

Notoriously, open star clusters often exhibit gaps in their MS -see for instance the study of Mermilliod (1976) and Rachford & Canterna (2000). It is possible to estimate the probability that a lack of stars in a mass interval is due to random processes by computing

$$P_{gap} = (\frac{m_{sup}}{m_{inf}})^{(-N \times x)} \tag{4}$$

where m_{sup} and m_{inf} are the border masses of the gap, $m_{sup} > m_{inf}$, x is the exponent of the Initial Mass Function (IMF) and N the number of stars above the gap, i.e with $m > m_{sup}$ (see Scalo (1986) and Giorgi et al (2001) for details). We derive star masses from the reddening corrected colors and magnitudes, finding that $m_{sup} \approx 9 M_\odot$ and $m_{inf} \approx 7 M_\odot$ (Girardi et al 2000).

The number of stars brighter than the gap is $N = 12$. By assuming a Salpeter (1955) IMF, with $x = 1.35$ we yield $P_{gap} = 8 \times 10^{-4}$. Since this value is very small, we therefore
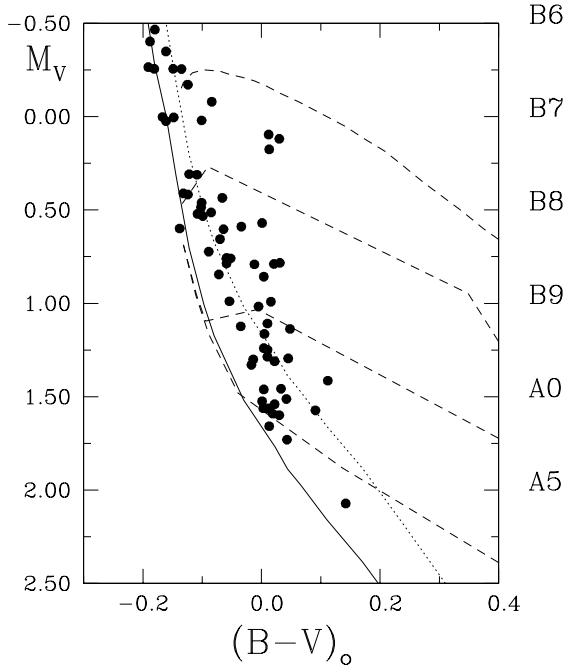
Figure 12. A zoom of the lower part of the reddening corrected CMDs. The solid line is a post MS isochrone for the age of 6 million yrs, the dotted line in the left panel is the same isochrone, but shifted by 0.70 to mimic the locus of unresolved binaries, and the dashed lines are from the bottom to the top pre MS isochrones for the ages of 2, 3, 5 and 7 million yrs.

conclude that the gap is a real feature.

The spectral type at the borders of the gap can be inferred from the absolute magnitudes and colours, which we derive in this case from Johnson (1966b), since Wegner (1994) does not report the absolute $(U - B)$ color. The upper border is defined by $M_V = -2.00$, $(B - V)_0 = -0.25$, $(U - B)_0 = -0.90$, which corresponds to spectral type $B1$; the lower border on the other hand is defined by $M_V = -1.00$, $(B - V)_0 = -0.15$, $(U - B)_0 = -0.52$, which corresponds to spectral type $B5$. We therefore conclude that the gap is the $B1 - B5$ gap, already found by other authors (Newell 1973), which could not be detected in previous photometric studies.

7.3 Pre MS candidates.

In Fig. 12 we propose a zoom of the lower part of the MS of the reddening corrected CMDs in the planes $V_o - (B - V)_o$. On the right we list the spectral type of the stars derived from the intrinsic magnitudes and colors (Johnson 1966b). Our aim is to compare the distribution of stars with pre MS isochrones to see whether the position of these stars is compatible with the possibility that they are in contracting phase toward the ZAMS. To this scope, we have superimposed a post MS isochrone (solid line) for the age of 6 million yrs, taken from Girardi et al (2000). In addition, we have overlaid three pre MS isochrones (dashed lines) taken from D'Antona & Mazzitelli (1994), and kindly provided by Paolo Ventura. From the bottom to the top they have ages of 2, 3, 5 and 7 million yrs.
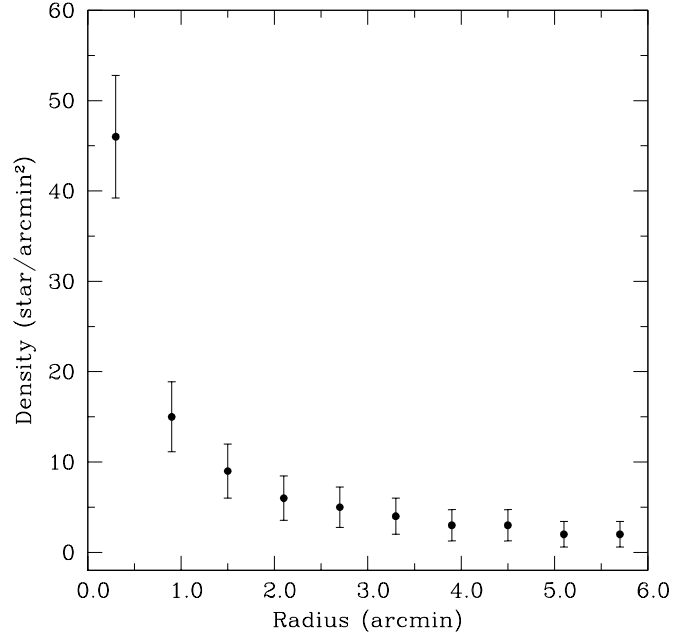
Figure 13. Density of stars in Trumpler 15 as a function of radius.

First of all we would like to note that the width of the MS here is much larger than photometric errors, which at these magnitude levels amount at $\Delta(B - V) \approx 0.04$ mag in color. The possibility that these stars are all binaries is ruled out as well, since the unresolved binaries isochrone, which lies only 0.70 mag above the 6 million yrs isochrone, encompasses only a fraction of these stars. To guide the eye we have drawn an 6 million yrs unresolved binaries isochrone as a dotted line in Fig. 12.

Finally, it is obvious that some of these stars can be field stars that we were not able to remove on the base of the sole reddening. However the mean reddening of the stars we have discarded (see Section 5) is $E(B - V) \approx 0.9$, very similar to that found by DeGioia-Eastwood et al (2001) for their background field.

This makes us confident on the reliability of the reddening criterion to disentangle cluster stars from field stars (see also Cudworth et al 1993 for a discussion on this subject).

In addition DeGioia-Eastwood et al (2001) find that Trumpler 14 and 16, two very well known clusters located basically at the same distance from the Sun as Trumpler 15 and probably coeval, exhibit pre MS stars starting from $M_V \approx 0.00$ ($Log\frac{L}{L_\odot} \approx 2.5$).

A nice feature in the CMD of Fig. 4 is the presence of a possible *turn-on* at $V \approx 14.5$, which corresponds to $(M_V \approx +1.00)$. These facts, together with the nice fit provided by pre MS isochrones suggests that indeed some of the stars with spectral types later than $B7 - B8$ can be in contracting phase. This would imply that a significant age spread is present in this cluster.

Deep near-infrared photometry and spectroscopy can help to cast more light on the nature of this population.

8 CLUSTER SIZE

Trumpler 15 appears very compact on sky maps (see also Fig. 1). According to WEBDA catalog, the cluster diameter is about $14'$, much larger than the region we covered.

We derived the surface stellar density by performing star counts in concentring rings around stars #6 (selected as cluster center) and then dividing by their respective surfaces. The final density profile and the corresponding poissonian error bars are depicted in Fig. 13. The surface density decreases sharply up to $\approx 2'$, then the decrease continues very smoothly. We can consider this radius as the core radius of the cluster. Inside this radius the cluster dominates stars counts, outside it smoothly merges with the field. A larger field coverage is necessary to give an estimate of the cluster radius, since members seem to be evenly present in the field we covered.

9 CONCLUSIONS

In this paper we have presented new $UBVRI$ CCD photometry for Trumpler 15, a young open cluster located in the Carina spiral feature.

We identify 90 photometric members on the base of individual reddenings, position on the CMDs and spatial distribution in the field.

Basing on this large sample we provide updated estimates of cluster fundamental parameters. We find that the cluster is young, with an age between 2 and 6 million yrs, contains a possible population of pre MS candidates, which deserves further investigation, and shows a gap in the MS at $V_o \approx 10.5$, that we suggest to be a real feature (the $B1-B5$ gap already found in other clusters).

We place the cluster at 2.4 ± 0.3 kpc from the Sun. Moreover we obtain $E(B-V) = 0.52\pm0.07$, and find that the extinction toward Trumpler 15 can be considered normal. Finally we estimate that the cluster has a core radius of about $2'$.

Trumpler 15 appears to be located somewhat closer to the Sun than Trumpler 14, Trumpler 16 and Collinder 232. Nevertheless, the data suggest that Trumpler 15 might belong to the complex defined by Trumpler 14, Trumpler 16, Collinder 232 and Collinder 228, since it shares with these clusters the same age and the presence of pre MS candidates. Moreover the extinction law seems to be basically normal (with some local fluctuations) in the entire region.

The most appealing scenario one can envisage is that all these clusters probably formed together in the same recent Star Formation event.

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